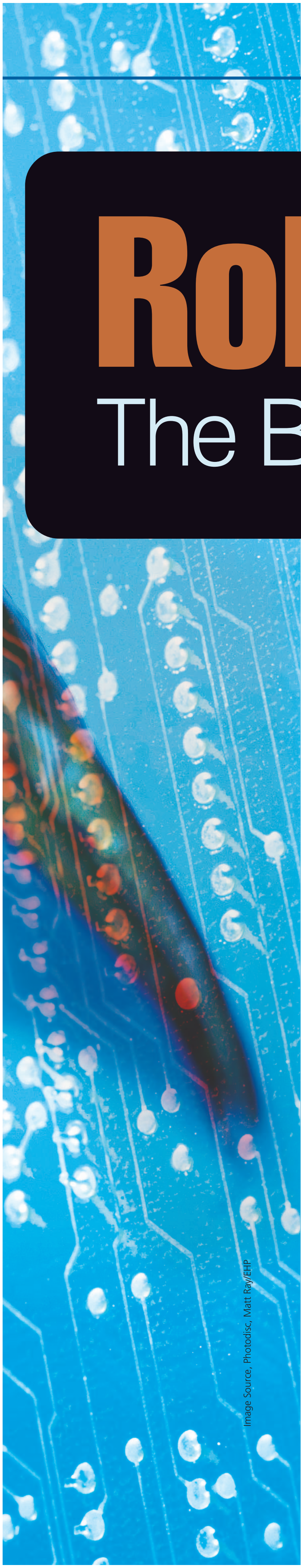


Image Source, Photodisc, Matt Ray/EHP

RoboLobsters
The Beauty of Biomimetics

Lobsters have a keenly developed sense of smell, which they use to detect and trace the odor of their food to its source in the ever-turbulent ocean. Scientists working in a new field known as biomimetic robotics believe that humans can solve real-world problems by dissecting this and other forms of animal intelligence, and then using that knowledge to design, build, and program autonomous machines with similar superhuman capabilities. Eventually, such robots could be used to track and pinpoint underwater sources of pollution, detect and locate mines and other unexploded ordnance, and even troll the ocean's depths for thermal vents and other locations offering untapped natural resources.

First, the Science

Neurobiologist Frank Grasso, an associate professor of psychology at Brooklyn College, is one of a growing number of biomimetics researchers. Grasso's principal aim is to advance scientific knowledge in the field. "We're not really in the business of developing new technologies," he says. "We're in the business of developing new understandings of the organization of controlled behavior."

Grasso works with lobsters in order to learn how they are so remarkably adept at tracking an odor to its source in a turbulent environment, and how to translate what is learned into new capabilities that humans can utilize. "Our understanding of fluid mechanics and the natural environment is poor compared to what the lobster is able to do with the kind of information that is out there," Grasso says. "The animals are capable of taking olfactory information and making decisions with it at a much faster time scale than we're able to understand right now."

By closely observing the lobsters as they sense and track large plumes of chemicals to their sources under controlled laboratory conditions, Grasso and his coworkers develop theories as to how they might be doing so. They incorporate those hypotheses into design parameters and programming for their robotic lobsters. "Then we test the robot under the same conditions as the animal, as a way of validating our theories as to how the animal is doing the tracking," he explains.

The autonomous robots only nominally resemble actual lobsters. The arrangement of sensors and the locomotion apparatus are intended to physically support the devices' programmed strategies, just as the animal's body and sensory organs are inherently interfaced with its neurological information processing and decision making.

Although physical resemblance itself is not a goal, a principle that Grasso calls "biomimetic scaling" is a critical factor in the experimental framework. Biomimetic scaling dictates that a robot need mimic the animal's biological characteristics only to the degree that those features support the concept being tested. For example, in a set of experiments reported in the 31 January 2000 issue of *Robotics and Autonomous Systems*, Grasso and colleagues designed and programmed a robot with known lobster values for body size and shape, sensor arrangement in space, speed and pattern of locomotion, and temporal and spatial resolution of the sensors in the robot's hardware and software.

The resulting robot is somewhat reminiscent of a lobster, but only insofar as those features allow the confirmation of the theories behind the mimicry. Evening the experimental playing field in this manner results in ongoing, interactive refinements of the hypotheses and the robots themselves as they improve in their ability to mimic real lobsters' behavior.

A Sense of Progress

A lobster's antennules, the extraordinarily sensitive chemosensory organs that protrude from its head, are responsible for the crustacean's superb sense of smell. "We've spent a lot of effort characterizing how the antennules move and how they sample in space," says Grasso. "You can observe them directly, and we've got a pretty good idea of what's going on there. The more important question is what's going on once the antennules' information passes through the brain, and how it's processed."

Robotics 101. Frank Grasso delivers a briefing onshore as students prepare for an underwater trial of the RoboLobster.

The very fact that lobsters can do what they do—overcome turbulence and efficiently track underwater odors to their source—proves that such an extremely complex problem can be solved, and Grasso is determined to find out how so that humans can duplicate the skill. He explains, "It's a matter of being able to ask the right questions of the lobsters and of any animal we study, to be able to constrain the models that we implement in the robots to be realistic in describing the transformations that the nervous system of the lobster produces." Ultimately, Grasso hopes the work will lead to plume-tracking systems that exceed even the lobster's innate abilities: "If we move toward the lobster's solutions, then along the way we may discover a turn that the lobster was evolutionarily unable to take, that we could exploit and use to develop even better systems."

Although they are far from ready to be deployed as marine pollution fighters or mine detectors, Grasso's robotic lobsters have demonstrated that the concept is valid and worthy of further investment of research funding and effort. His first robot, called RoboLobster, successfully tracked plumes from more than 32 feet in laboratory conditions, where the flow of the turbulence and plumes could be controlled.

In 2002, Grasso took a pair of second-generation robots to the Red Sea for a field trial. "We took the algorithms, the strategies that we had put into the robots, and tested them under uncontrolled conditions to see whether the intelligence we had extracted from the lobsters and put into the robots could actually bear up in the natural environment," says Grasso. "And remarkably, the robots didn't fall apart—they were able to track the plume with a comparable efficiency to what they had done in the laboratory." Although he notes that success in the Red Sea trials does not mean the robots were tracking exactly as their crustacean counterparts would, Grasso says the tests were a major validation of the operating principles at that point.

Pollution Patrol

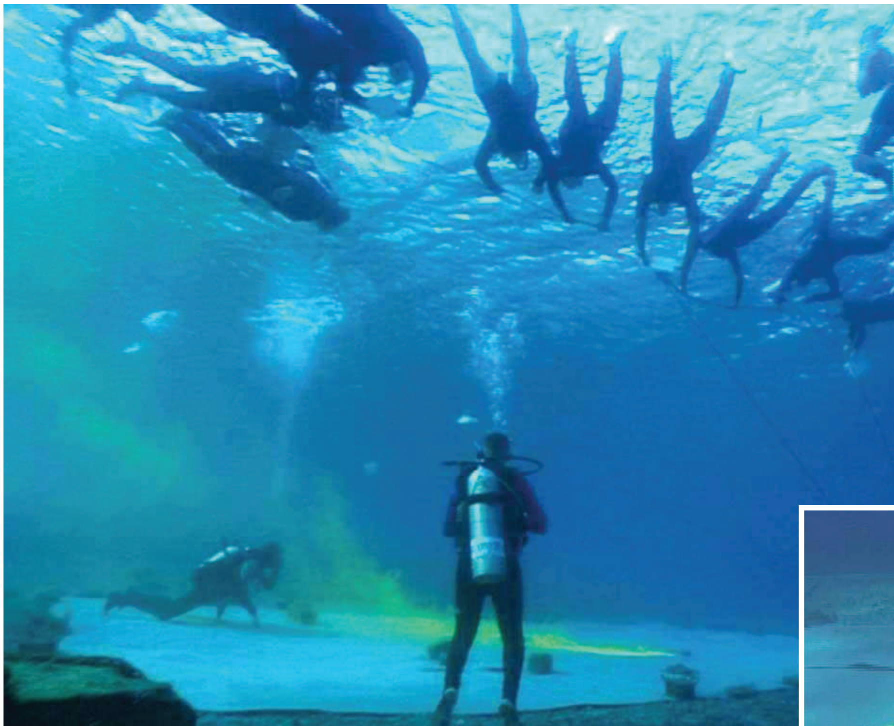
"Dr. Grasso's research may prove to be very important in the not-too-distant future for fighting pollution in our rivers, lakes, and oceans," says Roger Quinn, a professor of mechanical engineering at Case Western Reserve University. "Conceivably this control system can be used to guide robots as they patrol bodies of water to find possible pollutants and determine their source before great harm is done to the environment."

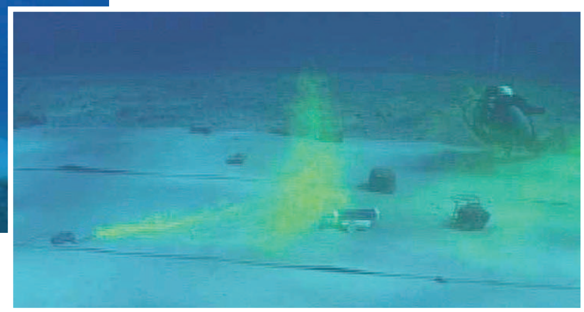
With most of his funding coming from the U.S. Navy, Grasso's principal charge is to develop the autonomous agents to detect unexploded mines, but he sees application of the technology to determine point sources of pollution as a natural extension of the robots' ability to sniff out and home in on the source of any chemical that leaves a trail. "[The ability to detect] the source of an odor could be applied to finding sources of pollution coming out of plants," he says. "You could even imagine tracking the wake of a leaky trawler or some other oceangoing vessel that had been polluting. The only limitation will be how smart we can make the robots, and how well we can make the sensors that are attuned to the things we want to track."

The next hurdle Grasso wants to address with biomimetics is how to track a moving target that generates a turbulent wake, such as that same leaky trawler. That adds several layers of difficulty to the challenge, and the lobsters and their robotic doppelgängers may not be up to it—because a lobster crawls along the ocean floor chasing stationary targets, its approach is basically two-dimensional.

Ariel Chaouat and Nadav Shashar/Interuniversity Institute of Eilat

Fish, on the other hand, perform that kind of three-dimensional tracking routinely as they detect and chase their prey, and they represent the next generation of robotics and study for Grasso's group. In this case, however, the researchers are building robotic fish that will allow study of the cues that predatory fish use to track fish. By mimicking the hydrodynamic and chemical disturbances made by a moving "bait" fish, the researchers hope to find out how predators track those cues to their sources. A first report from this work was published in the 19 June 2001 *Proceedings of the National Academy of Sciences*.





Crustacean demonstration. RoboLobster trials are conducted in the field at a depth of 5 meters (right; robot is in center of photo). Dye marks the substance to be sensed. Students score robot behavior by tracking its movements relative to the dye (above).

Ariel Chaouat and Nadav Shashar/Interuniversity Institute of Eilat

It's a more complex undertaking, because "the signal used in tracking a chemical to its source could be a mixture of the mechanical disturbance that's produced by the object itself—the source of the odor—and the chemicals that are streaming off of it," says Grasso. The clear question to be asked with this fish system, he says, is whether the fish are actually tracking chemicals or whether they are following the disturbance left in the wake. "It's most likely a ratio of the two," he adds, "and that leads to three-dimensional, multisensory integration, which is a really interesting and challenging problem."

A Biomimetic Zoo

It appears that almost any animal has unique qualities worth mimicking. Grasso, aside from his robotic lobsters and fish, is also working on modeling and building robotic octopi. The boneless tentacles of the octopus function like so-called soft actuators: the muscles alternately supply force generation and mechanical support to move objects along the length of the tentacle.

"If you've ever noticed," Grasso explains, "on the underside of an octopus, there are long rows of suckers, which the animal can rotate once they've grasped ahold of something, and they can walk the object along the length of the arm one way or the other. So there's a whole set of actuators that can be produced that are soft, flexible, and somewhat intelligent, because they can actually taste and feel the things that they're manipulating, and dynamically adapt to them."

Grasso's group is one of several involved in a large project designed to build biomimetic soft actuators capable of operating in a cluttered environment, maneuvering over and around objects, and then grabbing an object of interest and manipulating it. Eventually, a robotic octopus could be used to move through rubble to rescue earthquake victims, among other uses.

Pursuing a wide variety of practical applications as well as the scientific knowledge they yield, other researchers in biomimetic robotics have produced mechanical mimics of lampreys, cockroaches, crickets, flies, snakes, dolphins, scorpions, and more. Quinn's group, for example, has developed small robots mimicking the cockroach's locomotive system. Their devices use "whegs"—cockroach-like combinations of wheels and legs—to climb over obstacles. Quinn says Grasso's work "is of particular interest to us because we plan to develop highly mobile underwater robots based on our 'whegs' technology that could be outfitted with [a chemical sensing and tracking] system."

As the field progresses, and the many groups working in biomimetic robotics increasingly collaborate and combine their specialized technologies, it seems likely that in the near future we will routinely see machines exploiting for human use many of the advantageous features nature has bestowed on animals over millions of years of evolution.

Ernie Hood

Suggested Reading

Ayers J, Davis JL, Rudolph A, eds. 2002. Neurotechnology for Biomimetic Robots. Cambridge, MA: MIT Press.

Blazis DEJ, Grasso FW, et al. 2001. Proceedings of Invertebrate Sensory Information Processing: Implications for Biologically Inspired Autonomous Systems, 15–17 April 2000, Woods Hole, Massachusetts. Biol Bull 200(2):147–242.

Vogel S. 2001. Cat's Paws and Catapults: Mechanical Worlds of Nature and People. New York, NY: W.W. Norton & Company.

Webb B, Consi TR, eds. 2001. Biorobotics: Methods & Applications. Menlo Park, CA: AAAI Press.